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OIL RECOVERY PROCESS

Filed Aug. 22, 1955

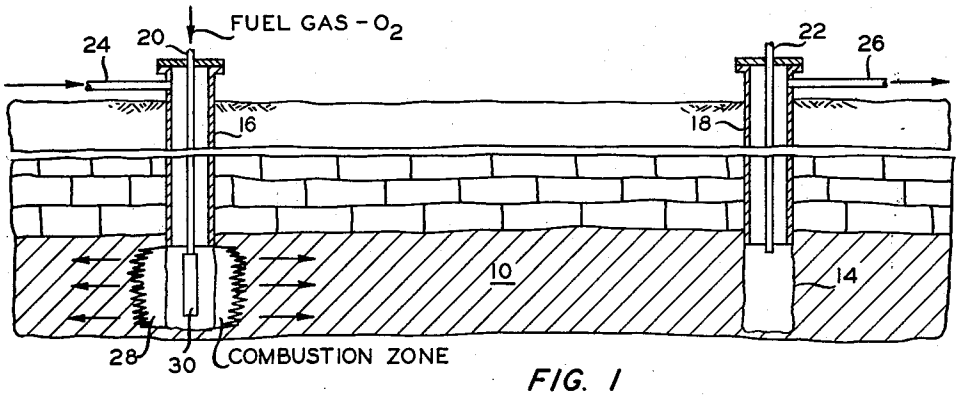

FIG. 1

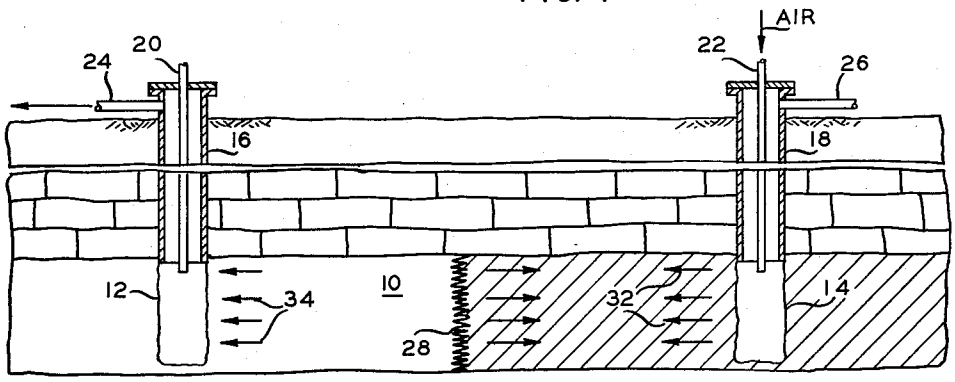

FIG. 2

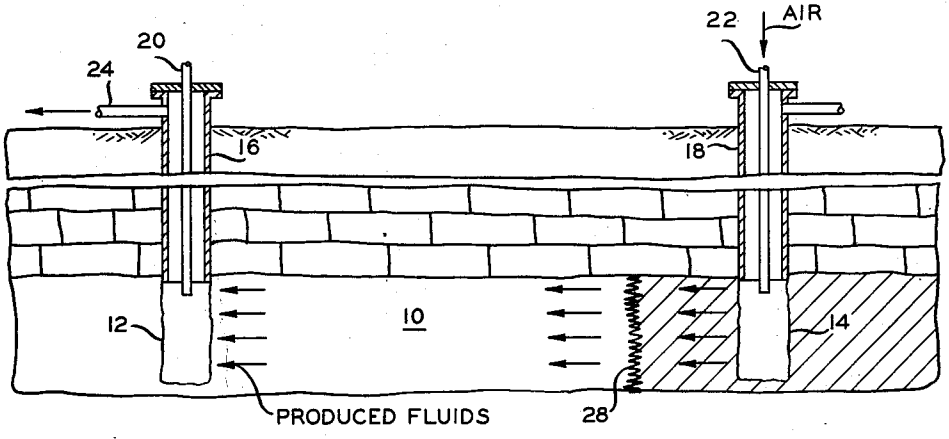

FIG. 3

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OIL RECOVERY PROCESS

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This invention relates to a process for the recovery or production of fluid hydrocarbons from underground formations containing hydrocarbon material, as applied to primary, secondary, or tertiary recovery programs. A specific aspect of the invention pertains to the recovery of hydrocarbon material too viscous to be readily produced by ordinary recovery methods.

A process known as "inverse air injection" in an in situ combustion method of recovering hydrocarbons from an underground hydrocarbon-containing formation is disclosed in the copending application of John Marx, entitled "Oil Recovery Process," Serial No. 526,388, filed August 4, 1955, now abandoned. In the disclosed method or process a fire front or combustion front is established in a formation surrounding a borehole in the formation by injection of hot combustion-supporting gas through the borehole into the formation (or by other suitable means) and after the combustion front has been established, the injection of air into the borehole is terminated and air or other combustion-supporting gas is injected into surrounding boreholes and forced to the combustion front or area so as to continue the combustion and advance the combustion front in a direction countercurrent to the flow of air to the burning area. If the injection of oxygen-containing gas is continued the combustion zone or front moves through the formation to the injection point or borehole. In this manner as the combustion front traverses the formation between the injection borehole and the borehole at which combustion was initiated, the fluid hydrocarbons freed from the formation by the combustion and the passage of hot gas through the burned-out area back of the combustion front are driven into the borehole in which combustion was initiated and are there produced or recovered in gaseous and liquid form by conventional methods. In this inverse air injection technique, as applied to an oil-bearing underground formation, the burned-out or coked area back of the flame or combustion front retains a substantial proportion of the hydrocarbon material driven out of the combustion area as the combustion front advances, even though the reverse injection method in in situ combustion produces from about 20 to 35 or 40 percent or more of the hydrocarbon initially present in the formation. Of course, a substantial portion of the hydrocarbon initially in place in the formation is consumed as fuel in the combustion process.

We have found that continued injection of air or other oxygen-containing combustion-supporting gas into the injection well or wells after the flame or combustion front has arrived at the injection well causes a reversal of the direction of the front and continued injection of the gas drives the front back to the area of initiation of the combustion and to the producing borehole, thereby substantially completely depleting the formation.

The principal object of the invention is to provide a process or method of recovery which recovers a substantial proportion of the hydrocarbon material remaining in an underground formation after recovery of hydrocarbon therefrom by inverse injection in situ combustion. Another object of the invention is to provide an oil recovery process which substantially completely depletes an underground oil-bearing formation of hydrocarbon material when applied to the formation after inverse injection of combustion-supporting gas in in situ combustion techniques. A further object is to provide an in situ combustion oil recovery method which substantially upgrades the hydrocarbon material contained in the formation and effects recovery thereof. It is also an object of the invention to provide a second-stage concurrent flow combustion recovery method which supplements inverse injection in situ combustion recovery to substantially deplete the formation. Other objects of the invention will become apparent from a consideration of the accompanying disclosure.

The present invention comprises continuing the injection of combustion-supporting gas into the injection borehole at the normal termination of the burning step in an inverse air injection process wherein the combustion or flame front is moved through the formation from the borehole in which combustion is initiated to the injection borehole countercurrently to the flow of the combustion-supporting gas, so as to reverse the direction of movement of the combustion front and drive the same back through the formation to the production borehole at which combustion was initiated. The process of reversing the direction of the combustion front is effected without reignition or supplying of heat other than that produced in the continuing combustion as the front reaches the injection borehole, i.e., the reversal is automatic with continuing injection of combustion-supporting gas. In this manner the coked material formed in the formation by the first stage combustion and/or the hydrocarbon material trapped by the burned-out area from the hydrocarbon-containing stream flowing to the production borehole from the combustion front are burned in part so as to substantially completely drive out all of the remaining hydrocarbon material from the formation and leave the formation substantially completely depleted of hydrocarbon material in the wake of the second stage combustion front.

In accordance with the process of the invention, combustion is initiated by any suitable means in a borehole in the hydrocarbon-bearing formation from which hydrocarbons are to be produced and after a combustion area surrounding the borehole has been established, injection of combustion-supporting gas such as air from one or more surrounding boreholes is commenced so as to force the gas through the formation to the combustion area and cause the combustion or flame front to move through the formation toward or to the injection boreholes. When the combustion front reaches the injection borehole, the flow of oxygen-containing gas is continued and the combustion front is driven in a reverse direction to the borehole in which combustion was initiated, thereby producing fluid hydrocarbons from the formation during both the first and second stage combustion and the hydrocarbon material is recovered from the borehole in which combustion was initiated. The produced hydrocarbons include the condensible hydrocarbon vapors produced by thermal decomposition or cracking in situ, as well as fluid hydrocarbon material rendered fluid by heat obtained from the combustion process.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURES 1, 2, and 3 are elevations in partial section showing a well arrangement for effecting the invention. Referring to the drawing oil stratum **10** is penetrated by a pair of wells **12** and **14**. Wells **12** and **14** are provided with casings **16** and **18** and tubings **20** and **22**, respectively. Casing **16** is provided with conduit **24** for injection or withdrawal of fluids from the annulus and casing **18** is provided with a similar conduit **26**.

In FIGURE 1 a heater or mass of charcoal **30** is positioned in well **12** and a fuel gas-air or oxygen mixture is supplied to the heater thru tubing **20** so as to heat the surrounding stratum to combustion supporting temperature. When this temperature is reached, air or other combustion-supporting gas is injected into the zone around

well 12 either thru conduit 24 as shown in FIGURE 1, or alternatively, thru conduit 26 or tubing 22, in which case a small concentration of fuel gas should be added to the injected gas. In this manner combustion zone 28 is established around well 12 in stratum 10.

Referring to FIGURE 2, this figure illustrates the phase of the process wherein combustion zone 28 is moving thru startum 10 from well 12 to well 14 as shown by the arrows leading from the combustion zone. The air or other combustion-supporting gas feeding the combustion zone is being supplied thru tubing 22, passing thru the stratum countercurrently to the movement of the combustion zone as shown by arrows 32. The combustion supporting gas can also be supplied thru conduit 26, if desired. During this phase of the process produced fluids pass thru the stratum into well 12 as shown by arrows 34 and production is recovered thru tubing 20 or conduit 24, as desired.

FIGURE 3 represents the stage of production after combustion zone 28 has reached well 14 and has been caused to reverse its direction and be driven toward well 12 as shown by the arrows adjacent the combustion zone. In this phase of the process, the combustion feeds on the coke deposited in the formation during the inverse drive or movement of the combustion zone from well 12 to well 14. Production during this phase of the process is recovered from well 12 in the same manner as illustrated in FIGURE 2.

It has been found that the in situ combustion process described herein raises the gravity of the original hydrocarbon in the formation from about 10° API to the range of 20 to 30° API depending upon the combustion temperature maintained in the formation during the movement of the combustion front therethrough and other factors, such as the nature of the formation. In one particular instance, an oil of 10° API was increased to 23° API at a combustion temperature of approximately 1000° F. and the viscosity of the produced hydrocarbon was approximately only half that expected of an oil of this gravity and only a small fraction of that of the original oil. It has been found that combustion can be adequately supported at temperatures in the combustion zone of about 750 to 800° F. on the first stage combustion and this temperature usually rises about 200 to 300° F. with substantially the same rate of air injection in the second stage combustion in which the flow of gas and combustion front are concurrent. Temperatures in the range of 1400 to 1600° F. have been maintained in the combustion front during the second stage combustion but the amount of cracking of the hydrocarbon material probably is substantially greater during inverse injection of air than that effected in the second stage combustion at significantly higher temperatures, due to driving the hydrocarbons ahead of the combustion front and not through it, as in first stage combustion.

Preferred operating temperatures in the first stage combustion (inverse air injection) are in the range of 750 to 1000° F., and in the second stage (concurrent air flow and movement of combustion zone) are in the range of 1000 to 1800° F.

In order to illustrate the invention, reference is made to a test made on a representative tar sand of approximately 8.0 weight percent tar saturation. The tar sand in particulate form was packed into a 1⅞" I.D., 304 stainless steel tube (18% chrome and 8% nickel) about 37" long by tamping the sand as it was placed in the tube. The tube was heat insulated to simulate underground conditions. Seven thermocouples spaced along the length of the tube projected into the sand at intervals of 2" and 4" between the first and second and between the second and third thermocouples, respectively, and there were 6" intervals between the third and fourth thermocouples and between each pair of succeeding thermocouples to the opposite end of the tube. A cap on each end of the tube was provided with connections and conduits for introducing and withdrawing gas from the tube so that air injection could be effected at either end of the tube and withdrawal of fluid effluent from the other connection could be simultaneously made from the opposite end. An electric heater was installed at a position close to the number 1 thermocouple and this electric heater comprised a porous disc positioned across the end of the tube so that gas passed through the heater before entering the sand. The current supplying the heater was turned on so as to warm up the heater and nitrogen was introduced to the heater-end of the tube and when the temperature at the first thermocouple reached 600° F. the flow of nitrogen was cut off and air was passed through the heater and into the sand. The temperature at the first thermocouple rose immediately, indicating that ignition or combustion of the tar had begun. The introduction of air was continued until the temperature rose suddenly at the second thermocouple, indicating that the combustion or flame front had reached this thermocouple which was approximately 2" from the end of the column of sand. At this point the injection of air was reversed so that the air traveled from the opposite end of the tube to the combustion front. The combustion continued with inverse air injection as indicated by the progression or advance of the combustion front to the third thermocouple. In due course the temperature rose in succession at thermocouples 4, 5, 6, and 7, indicating that the combustion front had moved completely through the column of sand. Air injection was continued and the temperature at the seventh and last thermocouple, adjacent the incoming stream of air, rather suddenly rose to approximately 1400° F. and then slowly dropped. Within a short time the temperature at thermocouples 6, 5, 4, 3, 2, and 1 rose in succession in that order to a temperature in the neighborhood of 1400° F., indicating that the combustion front had progressed back through the tube concurrently with the flow of air and gas therein. The effluent fluid was recovered from the end of the tube adjacent the No. 1 thermocouple for purposes of analyses.

During inverse injection of air (first stage combustion) the average flow rate of air was maintained in the range of 2000 to 2250 cc./minute and the average space velocity was 200 to 250 SCFH/ft.^{2} (standard cubic feet per hour per square foot of cross section). The temperatures recorded at the various thermocouples were in the range of 1000 to 1050° F.

During the second passage of the combustion front through the tube (second stage combustion) the air flow rate was maintained in the range of 2500 to 2900 cc./minute, amounting to a space velocity in the range of 270 to 320 SCFH/ft.^{2}. The temperatures during this stage as recorded at the various thermocouples were in the range of 1400 to 1470° F. Other runs were made with comparable results, indicating that a temperature in the range of 750 to 1000° F. may be readily maintained during the first stage combustion while a temperature in the range of 1000 to 1800° F. may be readily maintained during the second stage combustion.

The gravity of the original tar was found to be about 10° API and its viscosity was considerably greater than 100 centipoises. The hydrocarbon portion of the effluent obtained during inverse air injection (first stage combustion or first sweep) was found to have gravity of 22.1° API and a viscosity of 18.6 centipoises. The hydrocarbon effluent from the second stage combustion or second sweep had a gravity of 20.0° API and a viscosity of 53.7 centipoises. (API gravity at 60° F. and viscosity at 100° F.) These results are comparable to those obtained in other runs and are fairly typical.

Temperature control of the combusion zone may be effected by regulation of the flow rate of combustion-supporting gas and/or by varying the oxygen concentration therein. One effective method comprises admixing with air some of the combustion gas recovered from the production borehole or from other available sources.

Higher concentrations of oxygen (than in air) may be provided by conventional means.

It was surprising and unexpected to find that the reversal of the direction of travel of the flame or combustion front took place when the burning zone reached the end of the tube or packed column of tar-containing sand. Examination of sand taken from the packed tube, following an inverse air injection run and before the combustion front was passed through the tube in the opposite direction, revealed that considerable coke and trapped hydrocarbons are present in the sand. Examination of the sand taken from a packed tube after traversal thereof by the combustion front in both directions shows that the hydrocarbon material is substantially completely removed and the sand has the color of the formation with the hydrocarbon completely removed therefrom. In other words, the sand has substantially the same color as when the tar sand is calcined in the open in contact with air until all of the hydrocarbon material is removed and the sand is brought to its normal color. This indicates that the process of the invention is adapted to substantially completely deplete an underground formation at least in the accessible burning area thereof.

The process of the invention is applicable to the recovery of oil from formations which are amenable to recovery by inverse air injection in the in situ combustion technique. Hence, the process is applicable to primary, secondary, or tertiary recovery programs and is particularly applicable to the recovery of crudes too viscous to produce by other methods. A specific application is in the recovery of hydrocarbons deposited in shales and tar sands which present practically insurmountable difficulties when utilizing conventional recovery methods.

The original tar of the sand tested had a specific gravity of about 10° API and this was upgraded during first stage combustion recovery to approximately 23° API gravity and the recovered oil had a viscosity of 20 cp. at 100° F. or 106 secs. Saybolt.

The permeability of a formation may be increased, prior to application of the process thereto, by conventional means such as by hydraulic fracturing, with or without sand propping or propping with similar agent.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

We claim:

1. A process for recovering hydrocarbons from a gas-pervious underground formation containing hydrocarbon material which comprises initiating combustion of said hydrocarbon material in a restricted area of said formation adjacent a borehole therein so as to establish a combustion front; advancing said combustion front through said formation to an injection borehole by injecting a free oxygen-containing gas at less than combustion supporting temperature at the area of injection through said injection borehole and passing same to said combustion front; when said combustion front reaches said injection borehole, continuing the injection of oxygen-containing gas through said injection borehole so as to reverse the direction of movement of said front and drive said front a substantial distance toward said restriced area of initial combustion; and recovering hydrocarbons produced by the combustion and movement of the front toward and away from said injection borehole.

2. The process of claim 1 wherein the injection of free-oxygen-containing gas is continued until the combustion front is driven back to said restricted area.

3. In a process for recovering hydrocarbons in fluid form from a gas-pervious underground formation containing hydrocarbon material comprising establishing a combustion front in an area around a borehole in said formation; passing free-oxygen-containing gas at less than combustion supporting temperature at the area of injection to said combustion front from at least one injection borehole in said formation spaced apart from first said borehole so as to cause said combustion front to advance to said at least one injection borehole; and recovering fluid hydrocarbons driven from said formation through first said borehole; the improvement comprising reversing the direction of movement of said combustion front when same arrives at said at least one injection borehole by continuing the injection of oxygen-containing gas after said front reaches the borehole; driving said combustion front back toward first said borehole; and recovering fluid hydrocarbons from first said borehole as they are produced from said formation.

4. A process for recovering fluid hydrocarbons from a gas-pervious underground formation containing hydrocarbon material comprising establishing a combustion front in said formation around a borehole therein; injecting a free-oxygen-containing gas at less than combustion supporting temperature at the area of injection into said formation through a series of injection boreholes surrounding first said borehole and driving said gas to said combustion front so as to cause same to advance to said injection boreholes whereby fluid hydrocarbons are driven out of said formation from the area of the advancing front and are recovered through first said borehole, and residual hydrocarbon material is present in said formation after the combustion front has reached said injection boreholes; reversing the direction of movement of said combustion front after same has arrived at each of said injection boreholes in turn, by continuing the injection of oxygen-containing gas therethrough; and driving said front back to the vicinity of first said borehole by continuing injection of said gas so as to drive additional fluid hydrocarbons from said formation through first said borehole.

5. The process of claim 4 wherein said combustion front is established around first said borehole by injection of air preheated at least to combustion supporting temperature through first said borehole.

6. The process of claim 4 wherein the oxygen content of said gas is regulated so as to control the amount of hydrocarbon burned in said formation.

7. A process for producing fluid hydrocarbons from an underground gas-pervious formation containing hydrocarbon material which comprises intiating combustion in said formation adjacent a borehole therein; introducing an oxygen-containing gas to the combustion zone through said borehole so as to form a combustion front and advance same away from said borehole to produce a burned out area adjacent said borehole; thereafter injecting free-oxygen-containing gas at less than combustion supporting temperature at the area of injection into a plurality of surrounding boreholes so as to cause said gas to flow to said combustion front and advance same toward the injection boreholes whereby exhaust gases and produced fluid hydrocarbons are passed through the burned out zone behind said combustion front; as said combustion front reaches each of said surrounding boreholes, continuing the injection of said gas through each of said boreholes so as to reverse the direction of movement of said front and drive same back to first said borehole; and recovering through first said borehole fluid hydrocarbons produced during movement of said combustion front in both directions through said formation.

8. The process of claim 7 wherein hydrofracturing is applied to said formation to increase the permeability thereof prior to initiation of combustion therein.

9. The process of claim 7 applied to a formation as the initial recovery therefrom.

10. The process of claim 7 applied to a formation after primary recovery therefrom by a different technique.

11. The process of claim 7 applied to a tar sand formation.

12. The process of claim 7 applied to the recovery of a crude too viscous to be produced by other methods than countercurrent flow of gas and combustion front movement.

13. A method of recovering hydrocarbons from an

underground formation containing hydrocarbon material which comprises initiating combustion of said material in an area of said formation; advancing the combustion area so as to leave a burned-out area behind same; then forcing combustion supporting gas at less than combustion supporting temperature at the area of injection countercurrently to the advancing combustion area by injecting same through a borehole in said formation spaced a substantial distance from said burned out area; as said combustion front reaches said borehole reversing the direction of movement of same by continuing injection of combustion supporting gas therethrough; driving said front back to the area of initiation of same; and recovering fluid hydrocarbon material from said formation produced by combustion and gas flow.

14. The process of claim 7 wherein the combustion temperature during countercurrent flow of gas and combustion front is in the range of about 750 to 1000° F. and during concurrent flow is in the range of about 1000 to 1800° F.

15. A process for recovering hydrocarbons from a gas-pervious underground formation containing hydrocarbon material which comprises initiating combustion of said hydrocarbon material in a restricted area of said formation adjacent a borehole therein so as to establish a combustion zone; supporting said combustion by passing free-oxygen-containing gas at less than combustion supporting temperature at the area of injection to said combustion zone from an injection locus in a second area in said formation so as to cause the combustion to progress countercurrently to the flow of said gas to said injection locus leaving residual hydrocarbon material in the formation; when said combustion reaches said injection locus, continuing the injection of said gas so as to effect combustion of said residual hydrocarbon material and reverse the movement of the combustion zone; and recovering fluid hydrocarbons from the heated formation.

16. The process of claim 15 wherein injection of said gas is continued until the combustion of residual hydrocarbon material reaches the area of initial combustion.

17. A process for recovering fluid hydrocarbons from a gas-pervious underground formation containing hydrocarbon material comprising establishing a combustion zone in said formation around a borehole therein; injecting a free-oxygen-containing gas at less than combustion supporting temperature at the area of injection into said formation through a series of injection boreholes surrounding first said borehole and driving said gas to said combustion zone so as to support said combustion and cause same to advance to said injection boreholes whereby fluid hydrocarbons are driven out of said formation from the area of the combustion zone and are recovered through first said borehole, and residual hydrocarbon material is present in said formation after the combustion zone has reached said injection boreholes; reversing the direction of movement of said combustion zone after same has arrived at each of said injection boreholes in turn, by continuing the injection of free-oxygen-containing gas therethrough; and driving said combustion zone back to the vicinity of first said borehole by continuing injection of said gas whereby additional fluid hydrocarbons are driven from said formation through first said borehole.

18. A method for carrying out an underground combustion in an oil-bearing formation which is penetrated by at least two wells for the purpose of producing fluids therefrom, the steps of establishing communication between the oil-bearing formation and the ground surface through at least one injection well and one production well, pumping an oxygen-containing gas into said formation through said injection well, initiating combustion of said oil-bearing formation in the production well to form a combustion front to heat the oil therein and drive a portion of the components of said oil from said formation, a part of the combustible material originally in said oil-bearing formation being burned as the combustion front moves from the production well toward the injection well, continuing the pumping of oxygen-containing gas into said injection well after the combustion front reaches the injection well to cause the combustion front to move in the opposite direction until it has reached the production well again, and withdrawing the volatile unburned components of the oil from said formation through the production well.

19. In a process for the underground combustion of a carbonaceous deposit, said deposit being penetrated at spaced points by an injection well and a producing well, the improvement which comprises injecting into said deposit an oxygen-containing gas, initiating a zone of combustion therein at a point adjoining said producing well, thereafter supplying oxygen-containing gas through said injection well to said zone to maintain said zone and to propagate it through said deposit toward said injection well until said zone has reached an area adjacent the injection well, subsequently further introducing oxygen-containing gas into said deposit through said injection well whereby the course of said zone is reversed and travels concurrently with said gas toward said producing well, and recovering fluids resulting therefrom through said producing well.

20. In a process for in situ retorting of kerogen-containing oil shale in its natural formation, said formation being penetrated at spaced points by an injection well and a production well, the improvement which comprises injecting an oxygen-containing gas into said formation, initiating a combustion zone at a point in said formation remote from said injection well with heat front movement directed toward said injection well, thereafter supplying an oxygen-containing gas through said injection well for continuing heat front movement through said formation toward said injection well until said front has reached an area adjacent said injection well, then increasing the oxygen supply through said injection well for directing a reversing heat front movement toward said production well, maintaining the heat front temperature of said first pass lower than the coking temperature of the volatile components, increasing the temperature in the second heat front pass by increasing an oxygen input, and recovering fluids evolved at the heat front through said production well.

21. In a process for in situ retorting of oil shale in its natural formation, said formation being penetrated at spaced points by an injection well and a production well, the improvement which comprises injecting an oxygen-containing gas into said formation, initiating a combustion zone at a point in said formation remote from said injection well with heat front movement directed toward said injection well, thereafter supplying an oxygen-containing gas through said injection well for continuing heat front movement through said formation toward said injection well until said front has reached an area adjacent said injection well, in which movement shale is partially pyrolyzed and some volatile constituents are evolved from the organic content of the shale at non-coking temperatures, then increasing the oxygen supply in a fuel gas-air mixture introduced through said injection well for directing a reversing heat front movement through the pyrolyzed shale toward said production well, in an action in which some of the organic content of the shale is distilled, and recovering fluids evolved at the heat front through said production well.

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